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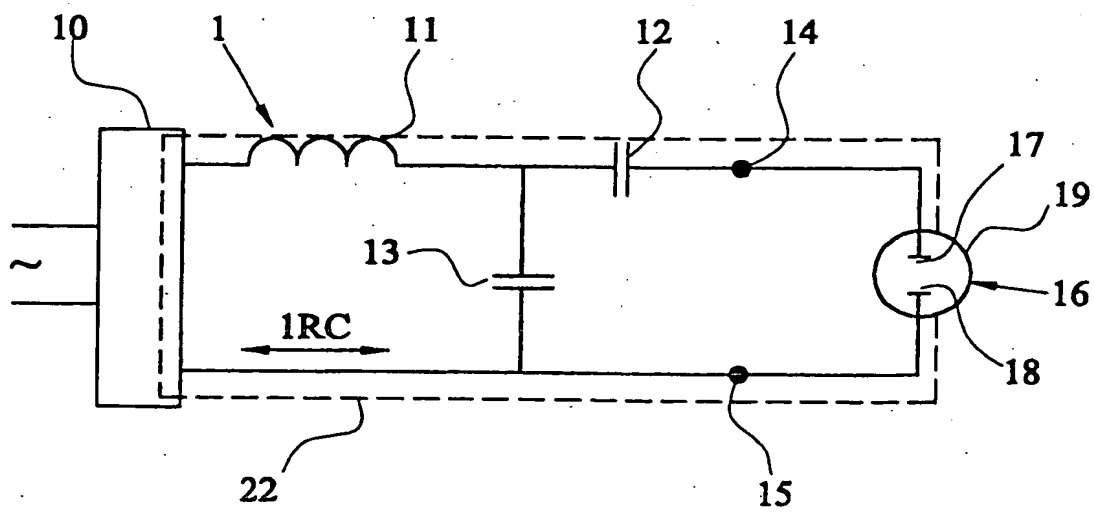
(57) Abstract

A lighting system (1) having a high intensity discharge lamp (16) and an electronic ballast having a variable frequency generator (10) which is arranged to vary the frequency of the ballast output over a range of frequencies having a minimum frequency of 400 kHz; a reactance is included in a joint operating circuit (22) in and between the ballast generator (10) and lamp (16) such that the circuit resonate to provide a starting voltage for the lamp at or above the minimum frequency. The arrangement inhibits lamp flickering and improves overall lamp and system efficiency.

Improvements to electronic ballasts

The present invention relates to electrical lighting systems and to electronic ballasts therefor for high intensity discharge lamps.

5   Such lamps have a high impedance before they are lit, and a low impedance while they are lit. High intensity discharge lamps are characterised by a short arc length, typically less than 20 mm for a 70 watt lamp, and have a sealed envelope containing at least two electrodes for an
10   electrical discharge, and typically have a high internal pressure when hot.

High intensity discharge lamps are in widespread use. A disadvantage of these lamps is that additional components are required for their proper operation. In particular a
15   means of limiting or controlling the current drawn by the lamp is required, together with a means of starting an arc discharge in the lamp.

The arrangements of components associated with the control of lamp current are commonly referred to as a
20   "ballast", whilst those components performing the function of starting the lamp are collectively referred to as the "ignitor".

Traditionally the ballast function was performed by a large and heavy inductor operating at the power line
25   frequency, whilst the ignitor function was performed by the generation of high (2-5kV) voltage impulses superimposed onto the supply terminals of the lamp.

More recently electronic means have been devised for operation of discharge lamps in order to overcome some of
30   the disadvantages associated with traditional methods of lamp operation. These disadvantages included size, weight, and a lack of any means of accurately controlling

lamp power with variations in supply voltage or frequency.

The electronic ballast means employed to date have been successful in overcoming the above mentioned
5   disadvantages, but as a result of their complexity, new disadvantages of cost and reliability have prevented their widespread use. It is convenient to describe such electronic ballasts as utilising "square wave technology" because of their output waveforms.

10   One of the reasons for the complex design of square wave technology ballasts, (which operate lamps at relatively low frequencies 50 - 400Hz for example), is that discharge lamps exhibit undesirable instabilities when operated in the frequency range of 1kHz - 300kHz.
15   Elaborate electronic topologies are required to generate low frequencies with power levels and control characteristics suited to discharge lamps.

Should the operating frequency (or some harmonic or sub harmonic of the operating frequency) be such as to excite
20   standing waves of pressure within a lamp then undesirable movement or even extinction of the arc can occur. This can be damaging to the lamp since arc movement can cause the arc to impinge upon the burner walls with consequent lamp failure. At the very least these movements of the
25   arc spoil the quality of illumination obtained.

The above mentioned instability and standing waves of pressure are manifestations of a phenomenon known as "acoustic resonance". Acoustic resonance arises as a result of pressure variations in the lamp caused by the
30   operating frequency or some harmonic or sub harmonic of the operating frequency.

According to the invention there is provided a lighting system comprising at least:-
a) a high intensity discharge lamp,
b) an electronic ballast having a regulated alternating
5 current power output,
c) a joint operating circuit included in and between the ballast and the lamp,
d) the ballast having a variable frequency generator which is arranged to vary the frequency of the ballast
10 output over a range of frequencies, with a minimum frequency of 400kHz,
e) the circuit having a reactance such that the circuit is arranged to be resonant to provide a starting voltage for the lamp at or above the minimum frequency.

15 A benefit of such a ballast is that it may be manufactured at low cost which when operating the discharge lamp has a high efficiency and reliability. A benefit of operating at a high frequency greater than 400kHz and greater than a maximum acoustic resonant
20 frequency of the lamp is that the life of the lamp and the quality of the illumination is improved by the avoidance of acoustic resonance.

Preferably a maximum frequency of the range is such that the power output is sufficient to maintain operation of
25 the lamp.

A benefit of restricting the frequency range is that stable operation of the lamp is ensured.

Preferably the ballast of the invention is arranged to regulate the power output to the lamp by varying the
30 frequency of the ballast output.

A benefit of arranging the ballast of the invention to control the power to the lamp is that the lamp may be operated at its optimal rating, and the effect of

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variations arising from manufacturing tolerances may be minimised.

Preferably the high intensity discharge lamp comprises a sealed envelope containing at least two electrodes for an
5　electrical discharge.

Preferably the ballast or frequency generator of the invention operates in a frequency range of between 400 kHz to 30MHz.　More preferably the frequency generator operates in a frequency range of between 400kHz
10　and 1,500kHz.

Preferably the ballast is arranged to provide a constant power to the lamp when it is running in a steady state, and a higher current during a starting phase of the lamp. Preferably the starting phase of the lamp is transient,
15　and of a short duration.

A benefit of providing a higher current during starting is that the lamp reaches its operating condition more quickly and reliably.

Preferably the ballast is arranged to limit the higher
20　current to a permissible value within a safe rating of the lamp.

Preferably the alternating current output wave form is of a substantially sinusoidal waveform with a harmonic distortion of less than 40%.

25　More preferably the substantially sinusoidal waveform has a harmonic distortion of less than 15%.

A benefit of an electrical output with a sinusoidal wave form is that a sine wave has only one fundamental frequency, compared with a square wave where a Fourier
30　analysis shows the square wave form to comprise a very large range of frequencies.　Hence in avoiding the excitation of acoustic resonance, with an output with a

sinusoidal wave form it is only necessary to avoid the
resonances that may be excited by one frequency.

A further benefit of a sine wave is that the rate of
change of voltage with time dv/dt is minimised. This
5   reduces the stress on electrical and electronic
components in the control, reducing a cause of failure.
A benefit of this is that the size of components may be
reduced, both reducing cost and size.

Another benefit of a sine wave is that the electrical
10   efficiency of the control is improved and hence the light
output from the lamp per power input is improved.

Preferably the frequency of the output may be varied
while the lamp is in a lit state.

A benefit of this is that by varying the frequency of the
15   output any excitation of acoustic resonance by a sub-
harmonic of the output frequency may be reduced.

Preferably the frequency of the output is varied at a
rate greater than 50Hz. A benefit of this is that any
acoustic resonance that may occur does not have an
20   opportunity to develop to an amplitude that would cause
an arc within the lamp to impinge on an internal surface
of a burner of the lamp. A further benefit is that the
perception of flicker caused by the variation of light
output arising from the change in lamp power arising from
25   such frequency variation is minimised.

An additional benefit of this is that although any
acoustic resonance is undesirable, lamps may withstand
such resonance provided that it is not allowed to develop
to such an amplitude that causes the arc to be deflected
30   onto the internal surface of the burner. When the arc is
deflected so that it impinges on the internal surface of
the burner damage is caused to the burner, and the life
of the lamp is reduced. Acoustic resonance of a lamp

frequently takes many hundreds of cycles before it has built up such an amplitude.

5 Preferably the reactance of the invention comprises a series arrangement of an inductance and a capacitor arranged so that the output frequency is above a resonant frequency of the reactance.

A benefit of this is that the reactance presents an inductive load to an output switching part of the 10 ballast. The output switching part may comprise at least two inverter transistors.

Preferably the ballast is arranged to provide the alternating current output by alternate switching of at least two inverter output transistors driven by a 15 discontinuous alternating waveform, the waveform containing a period within every half cycle when neither output transistor conducts.

A benefit of the discontinuous waveform is that the efficiency and reliability of operation of the 20 transistors and hence the ballast is enhanced.

Preferably the output power is arranged to pass through a capacitor in series with the lamp, the value of capacitance being sufficiently small to limit a current 25 flow, through the lamp at a frequency of the electrical power input to the ballast, to less than 30mA.

A benefit of this is that safety may be improved by preventing a hazardous current flowing from the terminal at a supply frequency.

30 Preferably the reactance comprises a control reactance in the ballast and a lamp reactance mounted to the lamp.

Preferably in an embodiment the reactance comprises a control reactance in the ballast and a lamp reactance mounted to a lampholder for receiving the lamp. Preferably removal of the lamp from the lampholder is arranged to disconnect the lamp reactance from the ballast.

Preferably a connection to the lamp is arranged so that the lamp can be replaced, and a capacitance is placed across the lamp in a parallel current path to the lamp, the capacitance being arranged such that disconnection of the lamp from the ballast output disconnects the capacitance from the ballast, the variable frequency generator being so arranged to sweep over a pre-determined range of frequencies to produce by means of a resonant circuit including the said capacitor a specific high frequency high voltage output to ignite the lamp.

Preferably the lamp reactance is mounted in thermal proximity to the lamp.

Preferably the electronic ballast comprises means for igniting the lamp, and preferably a required ignition voltage is generated by the reactance.

Preferably a value of the reactance and a value of a first lamp reactance have a combined value, and such values are arranged so that the ballast will be resonant only by means of the combined value. In an embodiment of the invention, preferably the value of lamp reactance is arranged so that a second lamp of a second power rating with a second value of lamp reactance will be such that the ballast will not be resonant when the second lamp is fitted to the circuit.

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A benefit of an embodiment of the invention is to overcome the disadvantages of cost and complexity associated with square wave technology so that a more widespread use of electronic ballasts, in conjunction with discharge lamps, is possible.

A benefit of an embodiment of this invention is that lamps may be operated with a substantially sinusoidal waveform of current at frequencies higher than any which would excite acoustic resonance in discharge lamps. A benefit of this mode of operation is that the complexity of the ballast is greatly reduced. A further advantage may be obtained by utilising reactive components already present within the ballast to generate the high voltages required for lamp ignition, thereby avoiding the need for a separate ignitor.

Specific embodiments of the invention will now be described by way of example with reference to the accompanying drawings in which:-

Figure 1 is a circuit diagram for operation of a lamp from a high power signal generator of a first embodiment of the invention;

Figure 1A is a circuit diagram of second embodiment of the invention for the operation of a lamp from a high power signal generator;

Figure 1B is a circuit diagram of third embodiment of the invention for the operation of a lamp from a high power signal generator;

Figure 2 is a circuit diagram of an electronic ballast according to a fourth embodiment of the invention;

Figure 3 is a graph showing a relationship between an open circuit lamp start voltage and frequency of an electrical supply across a lamp of the first embodiment shown in Figure 1;

Figure 4 is a graph showing a relationship between current through a lamp and the frequency of the electrical supply to the lamp of the first embodiment shown in Figure 1;

Figure 5 is a graph showing a phase angle relationship between a running current through a lamp and the frequency of this electrical output from the signal generator of the first embodiment shown in Figure 1;

Figure 6 is a is a graph of a relationship between a voltage across a lamp of the embodiment shown in Figure 1 before it is lit and up to the instant that it is lit with the frequency of an electrical supply across the lamp, and of a relationship between the said frequency and a current through the lamp from the instant it is lit and begins to conduct;

Figure 7 is a graph of a driving waveform for the output transistors for the embodiment shown in Figure 2;

Figure 8 shows an output waveform of the power output to the lamp at a preferred operating condition;

Figure 8A shows an output waveform similar to Figure 8, but at a non-preferred operating condition and resulting from the driving waveform of Figure 7;

Figure 9 is a graph of a driving waveform for the output transistors for the embodiment shown in Figure 2 at a higher frequency; and

Figure 9A is a graph of an output waveform resulting from the driving waveform of Figure 9.

Figure 1 shows operation of a lamp from a high power
5   signal generator 10 of a first embodiment 1 of the
    invention.   The generator has negligible internal
    impedance, produces a square wave voltage output of
    amplitude 350 volts, and has an output variable over a
    wide range of frequencies.   The wide range of frequencies
10 is preferably from 400 - 1,500kHz.   A high intensity
    discharge lamp 16 is coupled to the generator via an
    inductor 11, and a capacitor 12 at disconnection points
    14 and 15.   Lamp 16 comprises a sealed envelope 19
    containing electrodes 17 and 18 arranged for an
15 electrical discharge when the lamp is lit.   A further
    ignition capacitor 13 is provided.   A joint operating
    circuit 22 is included in and between the generator 10
    and the inductor 11 the capacitors 12 and 13 and the lamp
    16.   The operation of this circuit will now be described.

20 The initial conditions assumed are:

    1.   Output is available from the signal generator.

    2.   The signal generator has been set to its maximum
    output frequency.

    3.   That the lamp is not lit.

25 Table 1 below shows by way of example values of the
    inductor 11 and capacitor 12 which have been chosen to
    suit the power of the lamp used, which for this example,
    is 70 watts.

Table 1

Figure 1		Figure 1A		Figure 1B	
Inductor 11	76µH	Inductor 11A	76µH	Inductor 11B	76µH
Capacitor 12	11nF	Capacitor 12A	11nF	Capacitor 12B	11nF
	1.5nF	Capacitor 13A	1.5nF	Capacitor 13B	.75nF
Capacitor 13				Capacitor 21B	.75nF

Figure 3 shows a relationship between an open circuit
lamp start voltage versus a frequency of the lamp start
voltage. It may be seen that at a resonant frequency RF3
of inductor 11 and capacitor 13 of Figure 1 a high peak
voltage PV3 is generated. This voltage is arranged to be
sufficient to cause the lamp 16 to begin to conduct. The
resonant frequency RF3 is within the operating frequency
range 4R' between 4MF' and 4XF', which are the same as
the frequencies 4MF and 4XF and range 4F described below.

Figure 4 is a graph showing a relationship between
running current through the lamp 16 and the frequency of
the electrical supply from the signal generator 10 shown
in Figure 1. It may be seen that at the resonant
frequency 4RF of inductor 11 and capacitor 12 a high
resonant current 4PC is generated. To ensure that the
current through the lamp may be controlled, the signal
generator is arranged to operate over a frequency range
4R above a minimum frequency 4MF which is 400kHz or above
and below a maximum frequency 4XF. Using currently
available commercial components the maximum frequency
currently available is limited to about 500kHz, but

higher maximum frequencies would provide additional benefits relating to safety and operation described below.

Figure 5 is a graph showing a phase angle relationship
5   between a running current 1RC through a lamp 16 and the frequency of this electrical output from the signal generator 10 as shown in Figure 1. It may be seen from Figure 5 how the load on the output of the signal generator becomes inductive above the resonant frequency
10   of the inductor 11 and the capacitor 12. The operation of the signal generator may be made more efficient by operating in the inductive part of this graph, as is described with reference to Figure 2.

15

The value of 13 is chosen such that series resonance between 11 and 13 occurs at some series resonant frequency RF3 (of Figure 3) within the frequency range 4R' of the signal generator 10, but above the series
20   resonant frequency 4RF (of Figure 4) of 11 and 12.

Prior to ignition of the lamp the lamp will behave substantially as an open circuit so that no load is presented to the network of 11, 12 and 13.

The frequency of the signal generator is arranged to be
25   reduced until its output frequency corresponds to the above-mentioned series resonant frequency RF3 of 11 and 13. It is a characteristic of series resonant circuits that they exhibit low impedance at their resonant frequency. Thus a large current is driven, by the signal
30   generator, through the series resonant circuit formed by 11 and 13. As the lamp is still an open circuit no current passes through it, or the series connected capacitor 12.

This large resonant current flows through capacitor 13,
which has finite impedance. As a result of the finite
impedance of capacitor 13 and the large current flowing
5   through it, a high voltage PV3 is developed across
capacitor 13. Preferably the high voltage PV3 is in a
range between 500 volts and 50,000 volts. More
preferably for HID lamps the high voltage PV3 would be
between 2,000 volts and 5,000 volts. The lamp is
10 connected in parallel with capacitor 13 and as a result
of the high voltage present across the lamp, a gas in the
lamp breaks down and enters a glow mode of operation.
The lamp now no longer represents an open circuit and, as
a consequence, current begins to flow through the lamp.
15 The lamp voltage in this glow mode falls rapidly from the
open circuit value (2 - 5kV) to a very much lower voltage
of some 200 - 300 volts. Eventually the power being
dissipated in the lamp causes the lamp to transition from
the glow to the arc mode of operation. The low impedance
20 of the running lamp now shunts the capacitor 13. The
resonant action of capacitor 13 and 11 is highly damped
as a result. The extent of the damping is such that the
presence of capacitor 13 can be largely ignored once the
lamp is running. When the lamp is running in a steady
25 state it is lit and producing light in an efficient
manner.

Such a variation of voltage and current with frequency as
the lamp is switched on and starts to become lit and
continues lit can be seen from Figure 6. In Figure 6 a
30 combined graph of both voltage and current LTCV is
plotted against frequency FREQ. Such a graph may be
obtained from a circuit such as that shown in Figure 1.
Such a circuit may be arranged to comprise a variable
frequency generator. In operation when the circuit of

Fig. 1 is switched on the variable frequency generator
may be preferably arranged so that it starts operation at
a high frequency at a start point ST-ON. The variable
frequency generator may be arranged to then reduce the

5   frequency so that a voltage measured across terminals of
a lamp follows the arrow SW1. The voltage rises to a
maximum lamp voltage MLV at a particular frequency PF at
which point the lamp resistance breaks down and the lamp
suddenly begins to conduct. The voltage across the lamp

10   immediately collapses from the maximum lamp voltage value
MLV to a low value LLV. The voltage is no longer shown
on this graph, as it now varies with time rather than
with frequency. However, a lamp current LLC begins to
flow through the lamp at the instant the lamp begins to

15   conduct. Note that for clarity there is a gap shown on
the graph. The lamp current rises substantially
instantaneously to a maximum value MLC and then falls
rapidly to a point LC3 as the variable frequency
generator continues to reduce the frequency of the

20   voltage across the lamp. As the frequency continues to
fall the current rises to a second maximum at a dwell
point DWP. Preferably the variable frequency generator
is arranged to dwell for a considerably longer period
than a sweep time that has elapsed between the start

25   point ST-ON and the dwell point DWP. A benefit of the
dwell period is that the discharge in the lamp is allowed
to stabilise at the higher second maximum current before
the variable frequency generator reduces the frequency to
a sustained operation point SP. When the variable

30   frequency generator is operating at the sustained
operation point frequency SF the lamp is operating so as
to produce light in an efficient manner.

It is advantageous, in order to prolong lamp life, to
ensure that the lamp spends as little time as possible in
the glow mode of operation. Preferably the values chosen
for 11 and 12, such as those given in Table 1, in

5   conjunction with other design features present in a
practical embodiment of the ballast invention, provide
for a high current to be driven through the lamp whilst
it is in the glow mode. A benefit of this is that the
glow to arc transition period is minimised.

·10

Once the arc mode has become established the lamp
presents low impedance to the passage of current through
it. Initially, at start up, this impedance will be very
low. As the lamp warms up towards its final operating

15   temperature, the pressure of the lamp fill increases.
This brings about corresponding increases in lamp
impedance and lamp voltage during the warm up period.

As the current flowing through the lamp is determined

20   primarily by the series reactance of 11 and 12 and the
frequency of the signal generator, the frequency of the
generator may be adjusted to a minimum value so as to
obtain appropriate values of run up current and then
adjusted to provide a required steady state lamp current.

25

It will be noted that, when the lamp is running, lamp
current flows through the series connected components 11
and 12. Dependent upon the frequency of operation
chosen, three distinct modes of circuit operation exist.

30   Figures 4 and 5 show graphically the lamp current,
frequency and phase angle considerations

These three distinct modes are:

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1.   Where the operating frequency is above the series
resonant frequency of 11 and 12, the current drawn from
the signal generator will lag the signal generator
voltage by some phase angle, i.e. the signal generator
5   sees an inductive load.

2.   Where the operating frequency is below the series
resonant frequency of 11 and 12, the current drawn from
the signal generator will lead the signal generator
voltage by some phase angle, i.e. the signal generator
10   will see a capacitive load.

3.   Where the operating frequency is set at the series
resonant frequency of 11 and 12 the lamp current will be
essentially unlimited, as the overall impedance of the
supply circuit formed by the signal generator and the
15   components 11 and 12 will be at a minimum. The signal
generator will see an essentially resistive load in this
mode of operation.

Clearly the third mode of operation is not directly
useful, since it is the object of any practical ballast
20   to limit lamp current to some known and controllable
value. Limiting the output frequency range of the signal
generator is a practical means of ensuring that lamp
operation is only possible at frequencies usefully above
the series resonant frequency of 11 and 12, that is
25   operation preferably is constrained to mode 1.

By so limiting the output frequency range of the signal
generator to frequencies above the series resonant
frequency of 11 and 12, it is ensured that:

30   1.   Lamp current is controllable and follows some inverse
function of signal generator frequency.

2.   The signal generator is caused only to operate with an inductive load present at its output.

Both of these conditions are met in, but are not necessary to, a practical embodiment of the invention,
5   which utilises frequency control as the primary means of regulating lamp current (and therefore lamp power) to some chosen value.

It should also be noted, as a benefit, that any DC component of voltage present at the output of the signal
10   generator will be blocked from reaching the lamp by the action of the capacitor 12. In addition any tendency of the lamp to act as a rectifier will not result in a DC component of current flowing in the lamp. A benefit of this feature is that of preventing premature lamp failure
15   or damage to the ballast circuit.

A further benefit of capacitor 12 and the high frequency being above 400kHz, is that the value of capacitor 12 is sufficiently small to prevent a hazard from a supply frequency current that could otherwise be present at
20   lampholder terminals that is the points 14 and 15. Preferably the maximum current at the supply frequency is below a value which would present a hazard to persons who might come into contact with the lamp terminals. Preferably this value is less than 30mA, and more
25   preferably less than 5mA.

A fourth embodiment of the invention will now be described in detail with reference to the circuit diagram given as Figure 2, and the following Table 2 which gives suitable values for the components shown in Figure 2 for
30   a particular example of the fourth embodiment arranged to power a 70W high intensity discharge lamp, such as a Philips MASTERCOLOUR CDM-T (Registered Trademark) or a GE ARCSTREAM (Registered Trademark).

Table 2

Symbol	Value / Reference	Symbol	Value / Reference
D1	BAS216	Q1	BC849
D2	BAS216	Q2	BC849
D3	BAS216	Q3	FMMT720
D4	BAS216	Q4	FMMT720
D5	RB160L-40	Q5	IRML2803
D6	RB160L-40	Q6	IRF840
D7	RB160L-40	Q7	IRF840
D8	BAS216		
D9	RB160L-40		
D10	RB160L-40	U1	UC3861N
D11	RB160L-40		
D12	RB160L-40	T1	10:1 AUX POWER TRANSFORMER
D13	BAS216	T2	36:1 CURRENT TRANSFORMER
D14	BAS216	T3	7:11 GATE DRIVE TRANSFORMER
D15	UF5404		
D16	UF5404	L	76 MICROHENRY OUTPUT INDUCTOR
D17	UF5408	L1	20MH COMMON MODE INDUCTOR
D18	UF5408		
D19	UF4006		
D20	UF4006		
D21	BAS216		
D22	BAS216		
D23	15V ZENER		
BR1	4A 600V BRIDGE RECTIFIER		
R1	10kΩ	C1	10nF
R2	10kΩ	C2	10nF

R3	10kΩ	C3	100nF
R4	18kΩ	C4	100nF
R5	100kΩ	C5	12pF
R6	100kΩ	C6	100nF
R7	3.9kΩ	C7	10nF
R8	22kΩ	C8	220pF
R9	22kΩ	C9	100nF
R10	1MΩ	C10	100nF
R11	1MΩ	C11	100nF
R12	18kΩ	C12	100nF
R13	15kΩ	C13	100nF
R14	10kΩ	C14	3.3µF
R15	15Ω	C15	470pF/1kV
R16	15Ω	C16	470pF/1kV
R17	47Ω	C19	220pF
R18	47Ω	C20	220µF/200V
R19	47Ω	C21	220µF/200V
R20	827kΩ	C22	220nF/250VAC
R21	1MΩ	C23	220nF/250VAC
R22	180kΩ	C24	470µF/25V
		C	11nF/1kV
SR1	20Ω NTC	CIGN	1.5nF/6kV

All resistors 1%
All capacitors 5% voltage rating 25 vdc rating except
as stated

According to Figure 2 the power supply means to the invention is rectified and smoothed line frequency
5   current at a supply voltage of 230 vac (volts alternating current) (although the embodiment could also be arranged to work from a different voltage supply or from a direct current supply).

Components SR1, C22, L1, & C23 form a filter network that
10   prevents high frequency interference currents generated

by the circuit travelling back into the power line. BR1 is a full wave bridge rectifier and C20 and C21 are energy storing smoothing components.

5   This method of obtaining direct current from the power line is known to draw undesirable harmonic currents from the power line. The circuit stages involved namely BR1, a full wave bridge rectifier, and C20 and C22 the energy storing smoothing components may be replaced by an
10 "Active Power Factor Correction" circuit in order to overcome the above mentioned disadvantage. Such Active Power Factor Correction circuits are well known and documented in the art and may be employed without detriment to the function of the invention.

15 Rectified and smoothed line power is thus available at a voltage typically of 350 volts dc. This is the primary source of power for the embodiment to be described and will, for simplicity, be referred to as the 350-volt rail.

20 The 350 volt rail is connected and provides power to a zero voltage switching half bridge inverter circuit comprising Q6, Q7, D15, D16, D17, D18, C17 & C18. This inverter circuit supplies high frequency ac power to the lamp via 11 and 12. An ignition capacitor 13 is
25 provided. (The general functions of 11, 12 and 13 correspond with 11, 12, and 13 in the description given above with respect to Figure 1.)

The operation of the half bridge inverter circuit will
30 now be described with reference to Figure 2.

Transformer T3 in the circuit diagram performs the level shifting required to operate the gate of the "high side

transistor Q6. Components Q4, R15, D14 and C12 enhance
the gate discharge current available to Q6, whilst Q3,
R16, R17 & Q5 enhance the gate discharge current
available to Q7.

5   The driving waveforms thus made available to the power
switching elements Q6 & Q7 are arranged so as to be in
anti-phase thus Q6 is driven on whilst Q7 is biased off
and vice-versa. Moreover the drive waveform provides for
a dead space i.e. a small period of time between the
10 commutation of the conduction period of one transistor
and the onset of conduction of the other transistor.

From Figure 7, a graph of such a driving waveform for the
output transistors, the power switching elements Q6 and
15 Q7, for the embodiment shown in Figure 2 may be seen with
the voltage on the vertical axis and time on the
horizontal axis. The driving waveform 71 comprises a
square wave positive pulse 72 and a negative pulse 73,
separated by a zero voltage dead space 74, the negative
20 pulse followed by a second dead space 75. This is then
repeated at a time interval of 71T such that the
frequency of the waveform is greater than 400kHz. The
dead spaces have a time interval of 74T and 75T
respectively, and preferably this time interval is such
25 that the output transistors have sufficient time to cease
conducting, and also that the energy stored in the
reactance of the output circuit is sufficient to reverse
the potential of the output side of the output
transistors so that they do not have to switch any
30 voltage.

In the embodiment of Figure 2, 300nS has been found to be
an acceptable time interval for the dead spaces 74T and

75T with a whole cycle time interval 71T of 2µS at 500kHz.

Figure 8 shows an output waveform 81 of the power output to the lamp LP1 of Figure 2 at a preferred operating
5 condition. The preferred operating condition is such that when the first output transistor ceases to be driven at 84A, the stored energy in the output reactance L and C of Figure 2 is sufficient to produce the voltage change shown by line 84, such that at time 84B the voltage has
10 reversed completely and the second transistor begins to conduct to maintain the negative pulse until time 85A when the reactance again drives the voltage up line 85.

Figure 8A shows an output waveform 81' similar to Figure 8, but at a non-preferred operating condition and
15 resulting from the driving waveform of Figure 7. The non-preferred operating condition is such that when the first output transistor ceases to be driven at 84A', the stored energy in the output reactance L and C of Figure 2 is insufficient to produce the preferred voltage change, and
20 can only produce the voltage change shown by line 84', such that at time 84B' the voltage has not reversed completely and when the second transistor begins to conduct to maintain the negative pulse it has to increase the output potential by a step change 86', when it
25 maintain the voltage until time 85A' when the reactance again drives the voltage up line 85'. Again this is insufficient to completely reverse the voltage and the first transistor has to increase the output voltage by a step change 87'. These step changes in voltage are
30 undesirable.

Figure 9 is a graph of a driving waveform 91 for the output transistors for the embodiment shown in Figure 2 at a higher frequency and show how the dead space time intervals 94 and 95 must remain the same at 300nS to

allow the transistors to switch completely. However, from Figure 9A which is a graph of an output waveform 91'resulting from the driving waveform 91 of Figure 9, it maybe seen that due to the increased frequency there is
5   no longer sufficient energy in the output pulses 92 and 93 to enable the output reactance to store sufficient energy to completely reverse the voltage. Hence the voltage change 94' reaches a steady state voltage at 98 before the output transistor is driven, and hence the
10   output transistor has to increase the output voltage by step change 96. Similarly in the second half of the cycle, the voltage change 95' reaches a steady state voltage at 99 before the output transistor is driven, and hence the output transistor has to increase the output
15   voltage by step change 97.

This dead space serves two functions, the first is to ensure that Q6 & Q7 cannot conduct simultaneously and the second is to provide a time interval for the resonant
20   transition of current from one transistor to the other.

This resonant transition of current may provide considerable benefit to the electrical efficiency of the circuit, since by this means the considerable switching losses that normally occur in such a circuit are avoided
25   altogether.

The operation of this feature will now be described by comparison with a circuit that does not support resonant transition switching.

30   In a conventional inverter the power switching elements are not equipped with parallel capacitors C15 & C16. When one or other device commutates current, such current continues to flow in the device for a period of time

known as the "fall time". During such fall time the device supports simultaneously a high current and voltage which leads to high power dissipation during the commutation event. When the commutation events occur at

5   high frequencies, such as is the case in the present invention, considerable power is lost. This loss is commonly referred to as switching loss.

The introduction of C15 & C16 into the circuit can under

10   certain operating conditions, completely eliminate this switching loss. The important conditions are:

1. That a dead space is provided by the driving circuit waveforms.

2. That the load driven by the inverter is inductive in

15   nature and is of a certain minimum current.

As has already been stated a simple constraint in the operating frequency range will ensure that the operating frequency lies above the resonant frequency of 11 and 12 so that the inverter always drives an inductive load

20   during lamp operation. The above conditions are therefore met in this embodiment of the present invention.

In the resonant transition variant of the half bridge inverter capacitors C15 & C16 provide an alternative

25   pathway for the inductive current normally commutated by the power switching elements. When for example the driving waveform for the gate of Q7 goes to the low state Q7 ceases to conduct. Current continues to flow through the inductor 11 however, so that the current, which was

30   flowing in Q7 now commutates without loss into the capacitor C16. The direction of current flow is such as to charge C16 resonantly towards the upper 350-volt supply rail.

Sufficient time must be allowed in the dead space for this charging process to occur. The components C5 & R4 set the dead space period by way of a monostable internal to the control IC

5   The energy required to charge C16 in this manner is derived from energy stored in inductor 11. However inductor 11 stores more energy than is required to charge C16 to a voltage equal to the upper supply rail.

This additional energy is returned to the supply rail via
10   D17. D17 is in anti-parallel to Q6 and serves in conjunction with D16 to prevent the flow of current in the "body Diode" of Q6.

Exactly the same process occurs when Q6 commutates current into C15 during the opposite half cycle of
15   inverter operation.

The body diodes of power mosfet transistors have long reverse recovery times that lead to poor high frequency performance and device failure if the inverter circuit feeds capacitive loads. If the load is capacitive, for
20   any reason, then the body diode of one device can be conducting when the opposite device is turned on. This event causes very high currents to flow in both devices for the duration of the body diode reverse recovery period.

25   Although operation of the inverter is always into an inductive load, if the lamp is running, capacitive loads can be present during lamp ignition so that D15, D16, D17 & D18 are provided to eliminate the possibility of catastrophic transistor failures during lamp ignition.

30   Driving waveforms for the two inverter transistors Q6 & Q7 are preferably derived from a control IC available on the market, and manufactured by Unitrode Inc. of USA Type UC3861.

This IC performs a number of functions useful to the invention, although these functions may equally well be obtained from an alternative suitable circuit arrangement. The IC may be made sensitive to the prevailing lamp and supply conditions and can therefore be used to control the half bridge inverter circuit so as to start lamps, limit the range of operating frequencies, and to regulate the power of running lamps. The manner in which one embodiment of the invention utilises the control IC will now be described with reference to Figure 2.

Operating power for the control IC, U1, is derived from two sources, one source is utilised during circuit start up and relies upon a particular characteristic of the control IC. The other source is used to supply power to the IC in steady state operation with a running lamp. In this way a useful mode of lamp ignition is ultimately obtained.

The IC characteristic mentioned above is known as Under Voltage Lock Out (UVLO) which prevents operation of the IC when the supply voltage to the IC is too low for proper operation. When the IC is in the under voltage condition it is said to be below the UVLO start threshold. In this mode The IC draws a very low current from its supply.

Accordingly a high value of resistance from the 350-volt rail (R22 in Figure 2) will supply sufficient current to charge C24 to the upper UVLO threshold. (C24 is connected across the supply pins of the control IC). Once the upper UVLO threshold of the control IC has been reached the IC will become operational and draw a high current from the capacitor C24.

This capacitor is sized such that sufficient energy is stored in it to allow operation of the IC for some 20ms. During this period of operation the outputs of the IC will become active and drive the gates of the inverter

5   transistors Q6 & Q7. Once the inverter has become active a small auxiliary transformer T1 has its primary energised via a coupling capacitor C13. This transformer T1 has a 10:1 reduction ratio and its secondary is full wave rectified by D9, D10, D11, & D12. The rectified

10   output is applied across C24 so as to maintain a continuous supply of power to the control IC.

At the moment of power up the 5-volt reference pin of the IC becomes active and rapidly transitions between 0 and 5v. This transition is capacitively coupled to the base

15   of emitter follower Q2 via C10 so that the emitter of Q2 moves to an initial voltage of approximately 4.3 volts. As C10 charges the emitter voltage of Q2 falls towards 0 volts. The time constant of this circuit is set by R10. D8 ensures that C10 is immediately discharged if the 5

20   volt output of the control IC falls to zero. D8 thus provides a means of resetting C10.

The action of this part of the circuit is such as to force the voltage-controlled oscillator (VCO) internal to the IC to run at its maximum programmed frequency on

25   power up. As C10 charges and the voltage on the emitter of Q2 falls the VCO frequency falls towards the minimum programmed frequency. C8, R8 & R9 conveniently program the maximum and minimum frequencies of the VCO.

The output of the VCO is internally divided by two and

30   used as a clock for the IC outputs, so the overall effect of this sub-circuit is to cause the inverter output to sweep between a maximum and a minimum frequency at power up. The rate of this sweep is defined ultimately by the time constant of C10 and R10.

During this power-up frequency sweep at a particular
frequency PF a series resonance of 11 and 13 will be
excited, producing a burst of high voltage at the
particular frequency PF across the lamp terminals,
5   thereby breaking the lamp down into the glow mode of
operation.   The output frequency of the inverter will
continue to fall rapidly to the minimum programmed
frequency.   This will minimise the reactance in series
with the lamp thereby maximising lamp current, so as to
10   ensure a rapid glow to arc transition.   This sequence may
be seen from Figure 6, as described above.

Should the lamp fail to light, a time-out circuit
comprising C7 & R6 will cause the control IC to shut down
its outputs thus inhibiting the inverter activity.   The
15   time constant of C7 & R6 is preferably made small so as
to limit operation of the inverter to a short period of
time in this "ignition" mode.   Preferably the short
period of time is less than 10 seconds, and more
preferably less than 500 milli-seconds, and still more
20   preferably to less than 100ms.

This short period of time minimises the exposure of the
inverter transistors to the high dissipation conditions
that exist if the inverter is allowed to run continuously
without a lamp load.   Under these conditions the inverter
25   would be driving a capacitive load with consequent high
switching losses.

As soon as the action of the time out circuit has
inhibited inverter operation the auxiliary transformer T1
30   is deprived of power, so that this source of supply power
to the control IC is removed.   The current flowing
through R22 alone cannot sustain operation of the IC, so
that capacitor C24 becomes discharged.   Once the voltage

on C24 falls below the lower UVLO threshold the IC will revert to its low power mode and the charge cycle of C24 begins once more, leading to another power up ignition sequence. This process will continue until the lamp
5 eventually lights, or mains power is removed from the ballast.

This process provides an automatic means of lighting lamps which have become too hot to start as a result of a previous period of normal operation, without wasting
10 power in the ballast. Hot lamps have increased lamp fill pressures, which can elevate the voltages required for lamp ignition to undesirably high levels.

If the attempt to light the lamp was successful, lamp
15 current flowing through the primary of the lamp current sense transformer T2 causes a scalar current to flow in the secondary of T2. This secondary current is full wave rectified by D1, D2, D3 & D4. This rectified current produces a voltage drop across R1, the current sense
20 resistor. This voltage is proportional, therefore, to the lamp current. This voltage is applied to the base of Q1 via R7 so that if the lamp has started the time out circuit of C7& R6 is defeated by the action of Q1 and continuous operation of the circuit is allowed.

25 Once continuous operation has become established the function of the control IC becomes that of regulating lamp current and power.

In order to regulate lamp power both lamp current and lamp voltage must be sensed. Lamp current sensing is by
30 way of the current sense transformer T2 and the above mentioned current sense resistor.

Averaging components R2, C1, R3 and C2 present a signal
(I lamp average) to the control IC which is proportional
to the lamp current. An operational amplifier internal
to the control IC compares this signal with a set point
5   established by R13 & R14. In this way the lamp current
signal causes the frequency of the VCO to be increased or
decreased in order to maintain the set point current.
Components C11 & R11 are used to tailor the frequency
response of the operational amplifier so as to maintain
10   loop stability under all operating conditions.

Holding lamp current constant in this way would take no
account of the lamp power variations caused by lamp
voltage changes. Lamp power would be proportional to
lamp voltage. Accordingly the lamp voltage is sensed and
15   averaged by components C19, D21, D22, R20, C14, & D23.
Components D19 & D20 limit the lamp voltages sensed, so
as to prevent false operation during lamp ignition.

The signal thus derived is proportional to lamp voltage
and is resistively summed with the average lamp current
20   signal presented to the control IC via R12. In this way
the actual lamp current set point is reduced according to
increased lamp voltage, so as to obtain constant lamp
power operation over the anticipated range of lamp
voltages. This method is well known in the art and is
25   referred to as "linear Interpolation".

Over the normal range of lamp voltages, lamp power will
be held substantially constant by the use of this control
method. If however the lamp voltage falls outside of the
normal range, lamp power will deviate significantly from
30   the nominal value. In a preferred embodiment of the
invention, the lamp voltage and current signals are
summed in such a way as to reduce lamp power if the lamp
voltage falls outside of the normal operating range.

It is a characteristic of high intensity discharge lamps that, at end of lamp life, lamp voltage will deviate considerably from normal values. If the electrodes of the lamp have become eroded, for example as a result of extended operation, the lamp voltage will be increased as a function of the increased length of the arc discharge within the lamp. If the arc tube has developed a leak, or if lamp fill has been lost by some other mechanism, the lamp voltage will fall as a function of the reduced fill pressure within the lamp.

One disadvantage of high intensity discharge lamps is the risk of explosive lamp failure arising as a consequence of their high operating temperatures and pressures. The risk of this type of failure increases greatly if the lamp is operated beyond its rated life.

The risks of the lamp failing explosively in this way at the end of its rated lifetime are considerably diminished if the power supplied to the lamp is reduced. The action of the control method, which automatically reduces lamp power if lamp voltage falls outside of the normal range, is such as to reduce the risk of explosive lamp failure at end of lamp life.

Variations in the line power voltage have no effect on lamp power since the closed-loop feedback described above automatically compensates for such variations by adjusting the frequency of the inverter circuit so as to hold lamp power constant.

The response time of the operational amplifier internal to the control IC and associated external components is such as to allow the circuit to respond to the ripple voltages present on C20 & C21 which will be at twice the power line frequency.

The effect of this ripple voltage on lamp power is also therefore eliminated and any lamp power variations occurring at the second harmonic of the power line frequency will be eliminated. Such lamp power variations

5   can lead to visible lamp flicker, which is undesirable in many applications.

A further benefit arising from the above is that the inverter frequency becomes modulated as a function of the

10   second harmonic of the power line frequency. This frequency modulation spreads the ballast operation over a range of frequencies. This reduces the instantaneous sub-harmonic energies available to excite acoustic resonance in lamps and improves lamp stability. This

15   spread-spectrum operation also reduces radiated and conducted interference from the ballast, reducing the precautions needed to constrain such interference to acceptable levels.

20   Figure 1A shows operation of a lamp from a ballast or a high power signal generator 10A of a second embodiment 1A of the invention. The generator has negligible internal impedance, produces a square wave voltage output of amplitude 350 volts, and has an output variable over a

25   wide range of frequencies. The wide range of frequencies is preferably from 400 - 1,500kHz. A high intensity discharge lamp is coupled to the generator via an inductor 11A, and a capacitor 12A. Ignition capacitor 13A is provided, in series with a switch 20A which is

30   shown closed, but is arranged to open when the lamp 16A is disconnected from the joint control circuit 22A at disconnection points 14A and 15A. Lamp 16A comprises a sealed envelope 19A containing electrodes 17A and 18A

arranged for an electrical discharge when the lamp is lit. In operation this circuit functions in a similar manner to the first embodiment described above, except that when the lamp 16A is disconnected from the signal

5 generator, the switch 20A opens, hence capacitor 13A is no longer in a resonant circuit with inductor 11A, and hence the signal generator 10A is unable to produce the high ignition voltages that are required to start a lamp.

10 Figure 1B shows operation of a lamp from a ballast or high power signal generator 10B of a third embodiment 1B of the invention. The generator has negligible internal impedance, produces a square wave voltage output of amplitude 350 volts, and has an output variable over a

15 wide range of frequencies. The wide range of frequencies is preferably from 400 - 1,500kHz. A high intensity discharge lamp is coupled to the generator via an inductor 11B, and a capacitor 12B. Ignition capacitors 13B and 21B provided, ignition capacitor 21B. In this

20 embodiment switch 20B shown is omitted and the capacitor 21B is permanently connected in parallel with the lamp 16B. Hence when the lamp 16B is disconnected from the signal generator 10B at disconnection points 14B and 15B, the capacitor 21B is also disconnected from the signal

25 generator. Lamp 16B comprises a sealed envelope 19B containing electrodes 17B and 18B arranged for an electrical discharge when the lamp is lit. In operation this circuit functions in a similar manner to the first embodiment described above, except that when the lamp 16B

30 is disconnected from the joint control circuit, the capacitor 13B is no longer in a resonant circuit with inductor 11B, and hence the signal generator 10B is unable to produce the high ignition voltages that are required to start a lamp.

In an alternative embodiment to the third embodiment described above, the switch 20B may be inserted, and the lamp disconnection points arranged to be at the alternative locations 14B' and 15B'. Switch 20B being operable to an open state when the lamp 16B is disconnected from the ballast. Hence the operation of this circuit is similar to the fourth embodiment described above, in that when the lamp is disconnected from the ballast by disconnection at 14B' and 15B' the ignition capacitor 21B is removed from the resonant circuit and the signal generator 10B is not able to generate ignition voltages.

In the third embodiment of the invention the ignition capacitors 13B and 21B , resonate with the inductor 11 to provide the high voltages necessary for lamp starting. Ignition capacitor 21B may be situated separately or remotely from the ballast circuitry. As the capacitor is, in this embodiment of the invention, connected directly in parallel with the lamp 16B, no additional connections or wiring are required in order that this component can be situated at any advantageous location in the joint control circuit 22B between the ballast or signal generator 10B and the lamp 16B.

Preferably this capacitor is located in whole or in part, proximate to the lamp or is incorporated into the structure of the lamp, so that the following disadvantages that relate to discharge lamp operation may be reduced or eliminated.

These disadvantages, in part, relate to the safe operation of equipment that utilises discharge lamps. Such equipment normally makes use of a socket arrangement for connection of the discharge lamp in order to facilitate lamp changes. The high voltages normally generated during lamp starting can be hazardous,

particularly in respect of operation with no lamp present
in the lamp socket. The high starting voltages present
at the receptacles of an exposed lamp socket give rise to
the risks of, for example, electric shock.

5   If this capacitor is located in whole or in part in the
structure of the lamp or its base, then the resonant
action necessary for the generation of high lamp starting
voltages cannot occur, unless a lamp possessing an
appropriate value of parallel capacitance is properly
10   fitted into the lamp socket. By this means greater
safety is imparted in respect of operation with missing
lamps.

Another disadvantage of known arrangements relates to the
fact that discharge lamps are available with more than
15   one power rating, but utilising the same base. As a
result of this it is possible, for example to insert a
low power, say 35W lamp, into a socket that is intended
for a 150W lamp. As a result of this the 35W lamp is
grossly over powered and will almost certainly fail
20   explosively within a few minutes of start-up.

In order to overcome this mismatching of lamps and
sockets the fractional proportioning of the ignition
capacitance between capacitor 13B that is permanently
connected to the ballast circuit and the capacitor 21B
25   that is disconnectable with the lamp may be made such as
to prevent resonance occurring between high power
ballasts and low power lamps. In this way low power
lamps will not start when connected to ballasts intended
for operating high power lamps, since the electrical
30   conditions required for resonance will not be met. By
this means of matching lamp reactive parameters to
ballast reactive parameters improved safety and
reliability are achieved.

A further advantage may be obtained if the capacitor 21B is thermally coupled to the lamp. It is well known that many types of discharge lamp cannot be restarted whilst

5 they are hot. During a period of normal operation the lamp will become hot and cannot be restarted until it has cooled to a sufficiently low temperature. Any attempt to restart the lamp will be unsuccessful until the lamp has cooled to a temperature such that its starting voltage

10 requirement has fallen within the capability of the ballast to provide a sufficient starting voltage.

It is the case therefore that the ballast may make a very high number of unsuccessful attempts to restart a hot lamp. These attempts represent unnecessary electrical

15 stress throughout the system. It is normal practice in the industry to fit timer systems to overcome this difficulty.

If the capacitor 21B is thermally coupled to the lamp in such a way that capacitor temperature closely follows

20 lamp temperature and the capacitor construction is such that it has a large negative temperature coefficient of its value, then the capacitance will fall in value with increasing lamp temperature.

If this decrease in capacitance is such as to prevent

25 resonance occurring when lamps are too hot to restart, then the lamp (and capacitor) must cool sufficiently before resonance and lamp starting can occur.

By this means unnecessary and stressful attempts to start a hot lamp are automatically inhibited until the lamp has

30 cooled to an appropriate degree.

CLAIMS

1. A lighting system comprising at least:-

   a) a high intensity discharge lamp,

   b) an electronic ballast having a regulated alternating current power output,

   c) a joint operating circuit included in and between the ballast and the lamp,

   d) the ballast having a variable frequency generator which is arranged to vary the frequency of the ballast output over a range of frequencies, with a minimum frequency of 400kHz,

   e) the circuit having a reactance such that the circuit is arranged to be resonant to provide a starting voltage for the lamp at or above the minimum frequency.

2. A lighting system as claimed in claim 1 wherein the ballast is arranged to regulate the power output to the lamp by varying the frequency of the ballast output.

3. A lighting system as claimed in claim 1 or 2 wherein a maximum frequency of the range is such that the power output is sufficient to maintain operation of the lamp.

4. A lighting system as claimed in any one of claims 1 to 3 wherein the range of frequencies is from 400kHz to 1,500kHz.

5. A lighting system as claimed in claim 3 wherein the ballast power output is regulated so that the output provides a constant power to the lamp when it is

running in a steady state, and a higher current during a starting phase of the lamp.

6. A lighting system as claimed in any one of the preceding claims wherein the alternating current is of a substantially sinusoidal waveform with a harmonic distortion of less than 40%.

7. A lighting system as claimed in claim 6 wherein the substantially sinusoidal waveform has a harmonic distortion of less than 15%.

8. A lighting system as claimed in any one of the preceding claims wherein the reactance comprises a series arrangement of an inductance and a capacitor where the output frequency and the value of the reactance is arranged so that the output frequency is above a resonant frequency of the reactance.

9. A lighting system as claimed in claim 8 wherein the ballast is arranged to provide the alternating current output by alternate switching of at least two inverter output transistors driven by means to provide a discontinuous alternating waveform, the waveform containing a period within every half cycle when neither output transistor conducts.

10. A lighting system as claimed in claim 8 or 9, wherein the output power is arranged to pass through a capacitor in series with the lamp, the value of capacitance being sufficiently small to limit a current flow, through the lamp at a frequency of the electrical power input to the ballast, to less than 30mA.

11. A lighting system as claimed in claim 1, wherein a connection to the lamp is arranged so that the lamp can be replaced, and a capacitance is placed in a parallel current path to the lamp, the capacitance being arranged such that disconnection of the lamp from the ballast output disconnects the capacitance from the ballast, the variable frequency generator being so arranged to sweep over a pre-determined range of frequencies to produce by means of a resonant circuit including the said capacitor a specific high frequency high voltage output to ignite the lamp.

12. A lighting system as described with reference to the accompanying drawings.
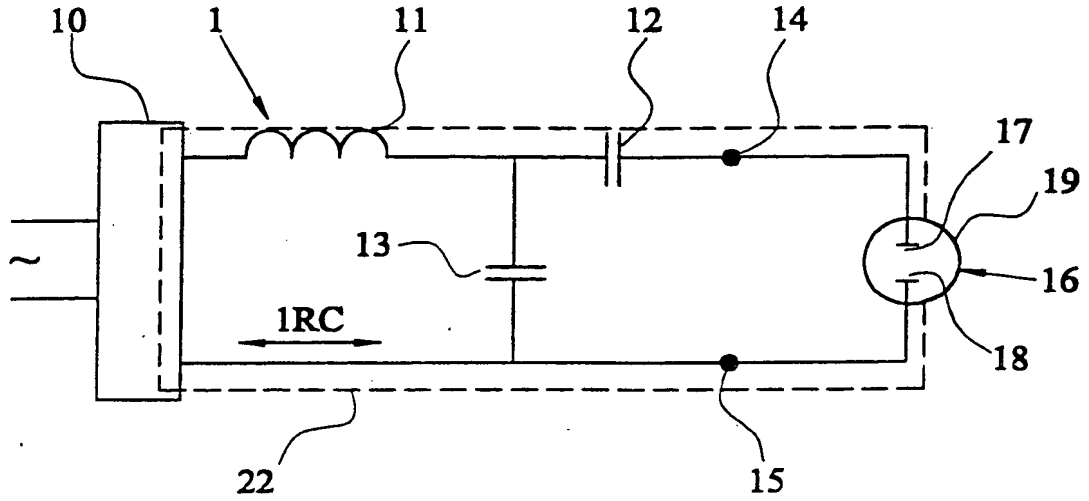
FIG. 1
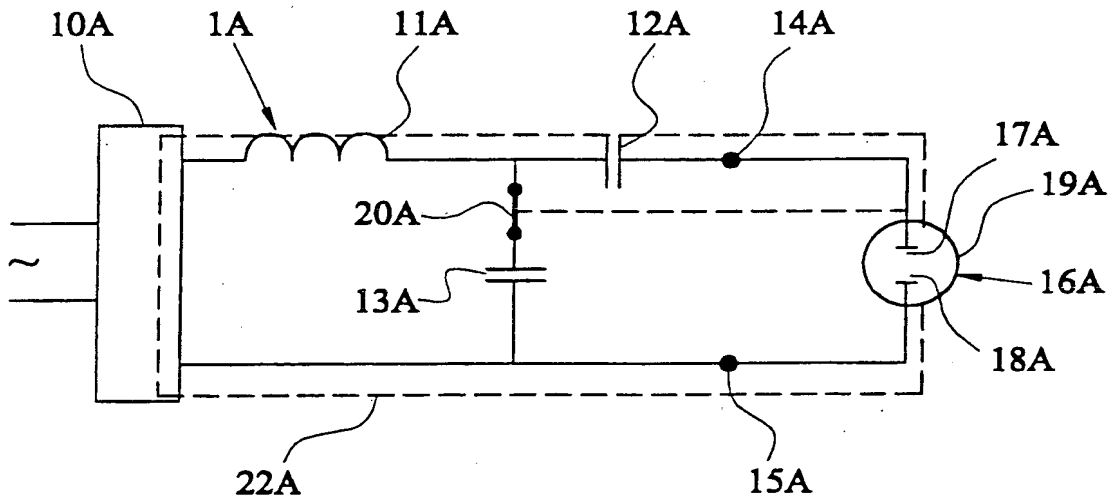
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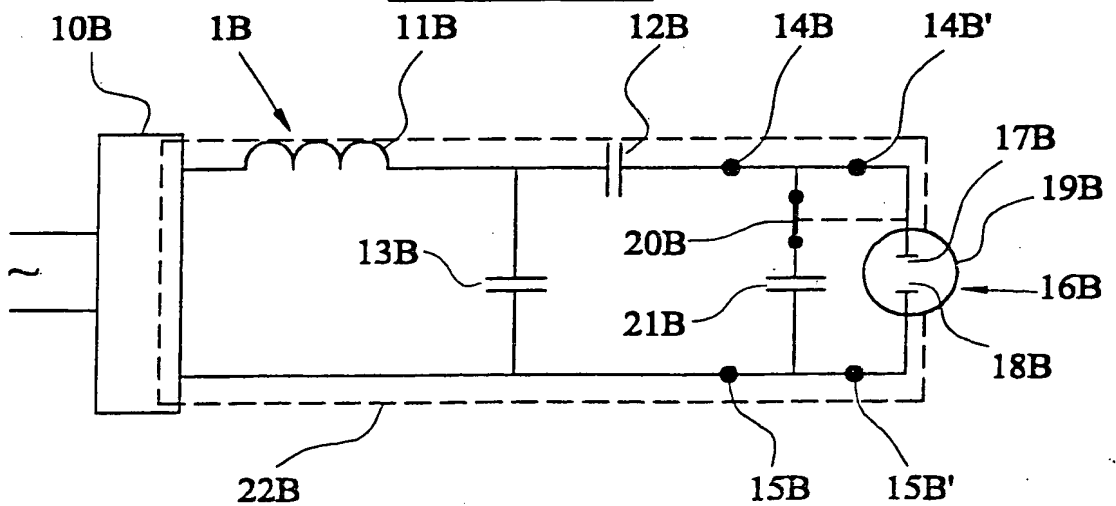
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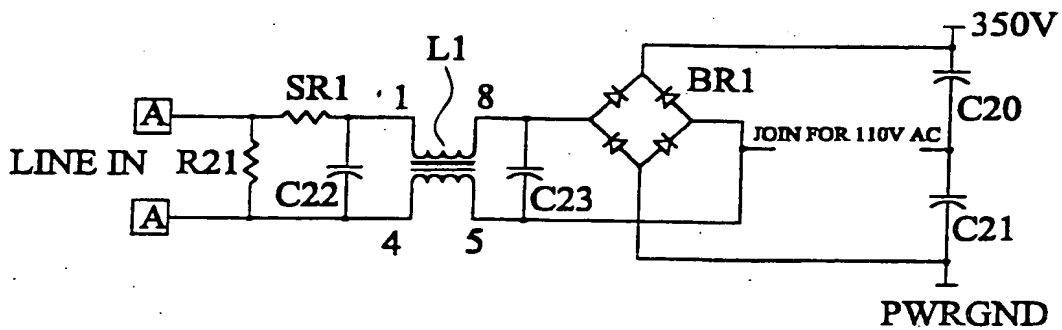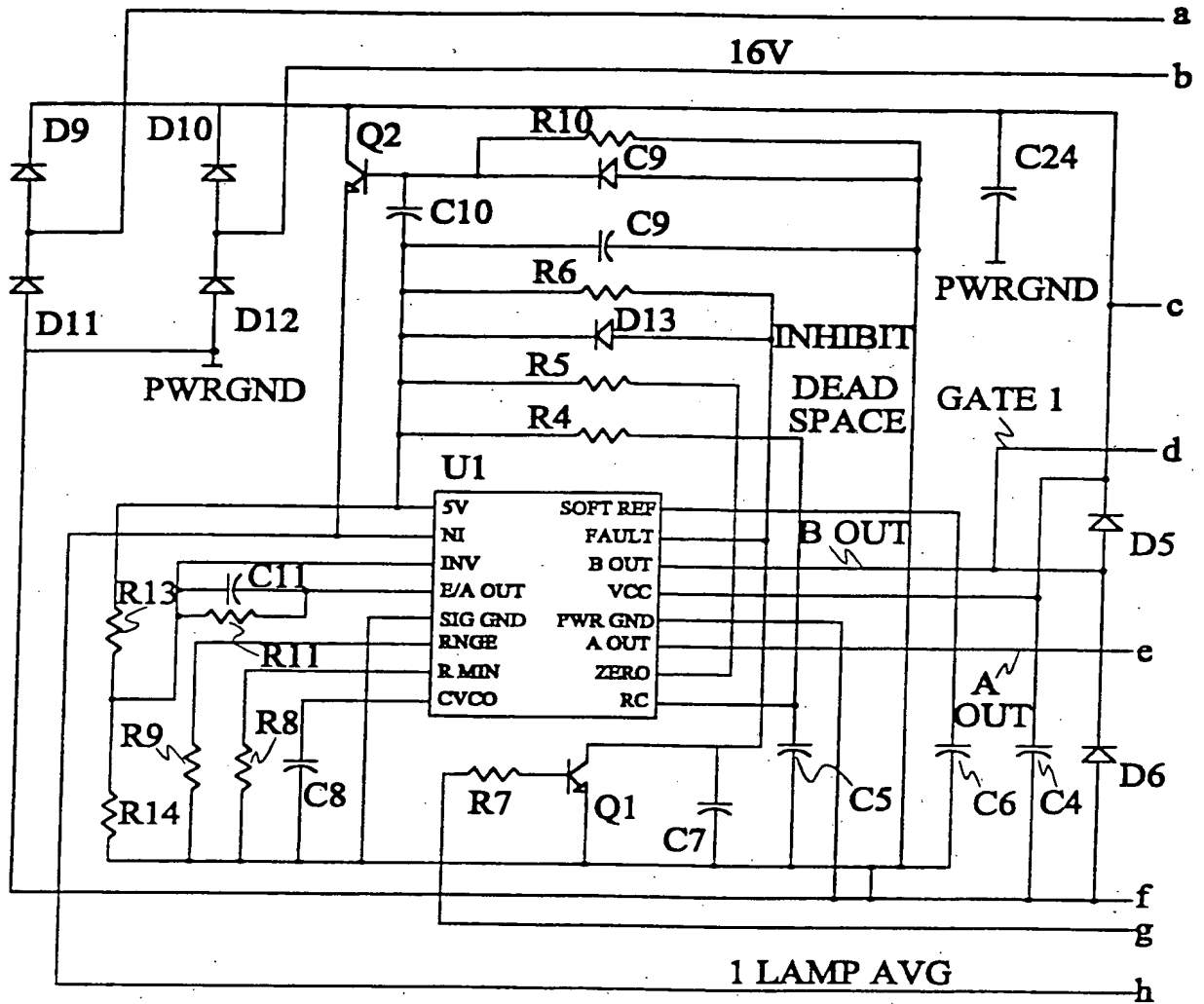
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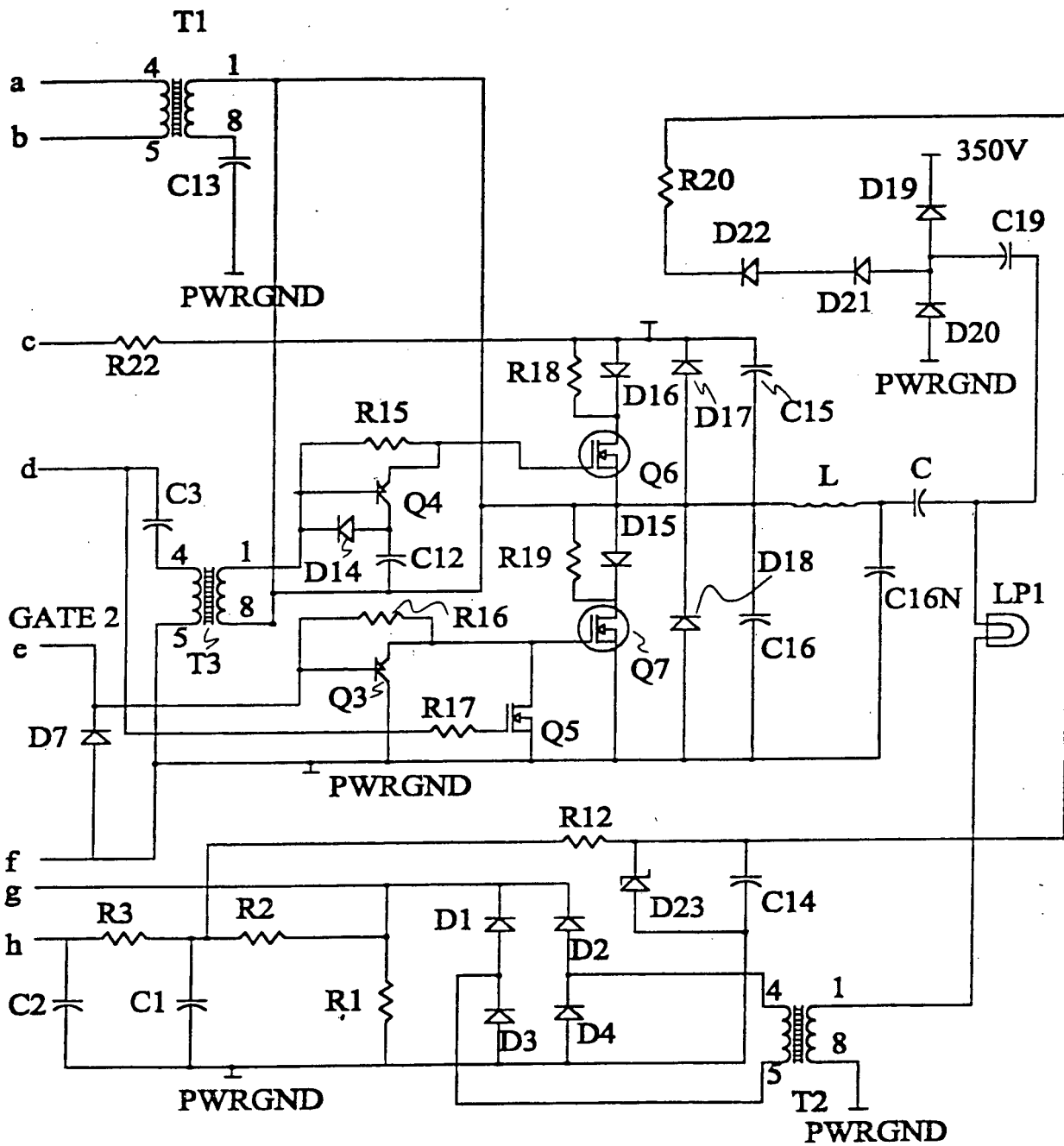
FIG. 2 (cont.)
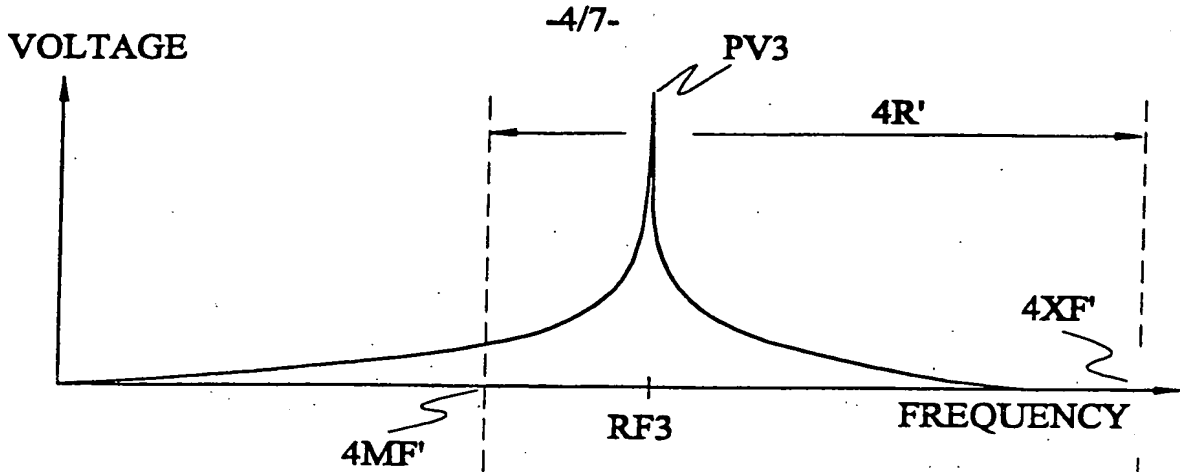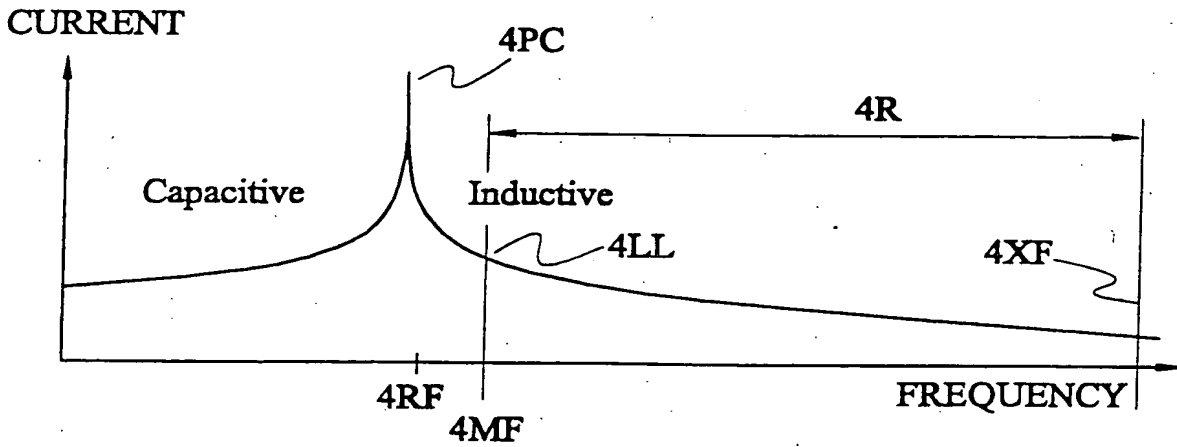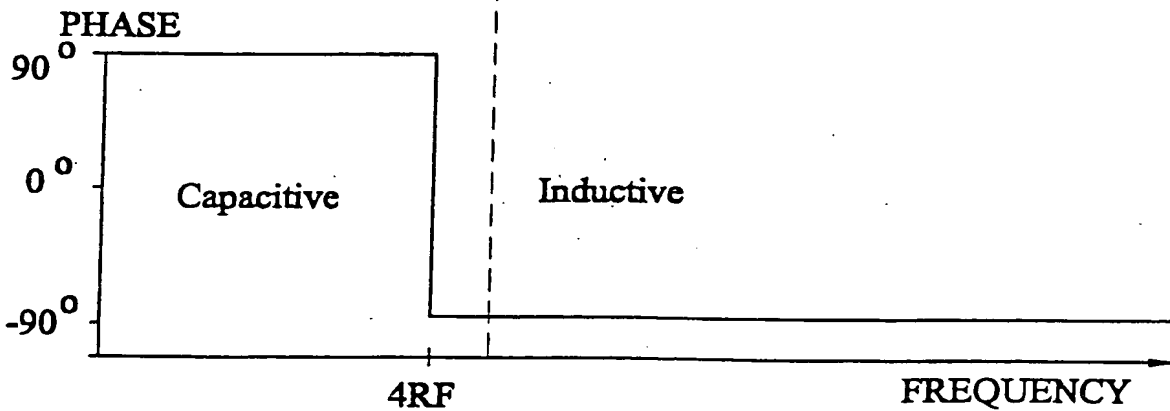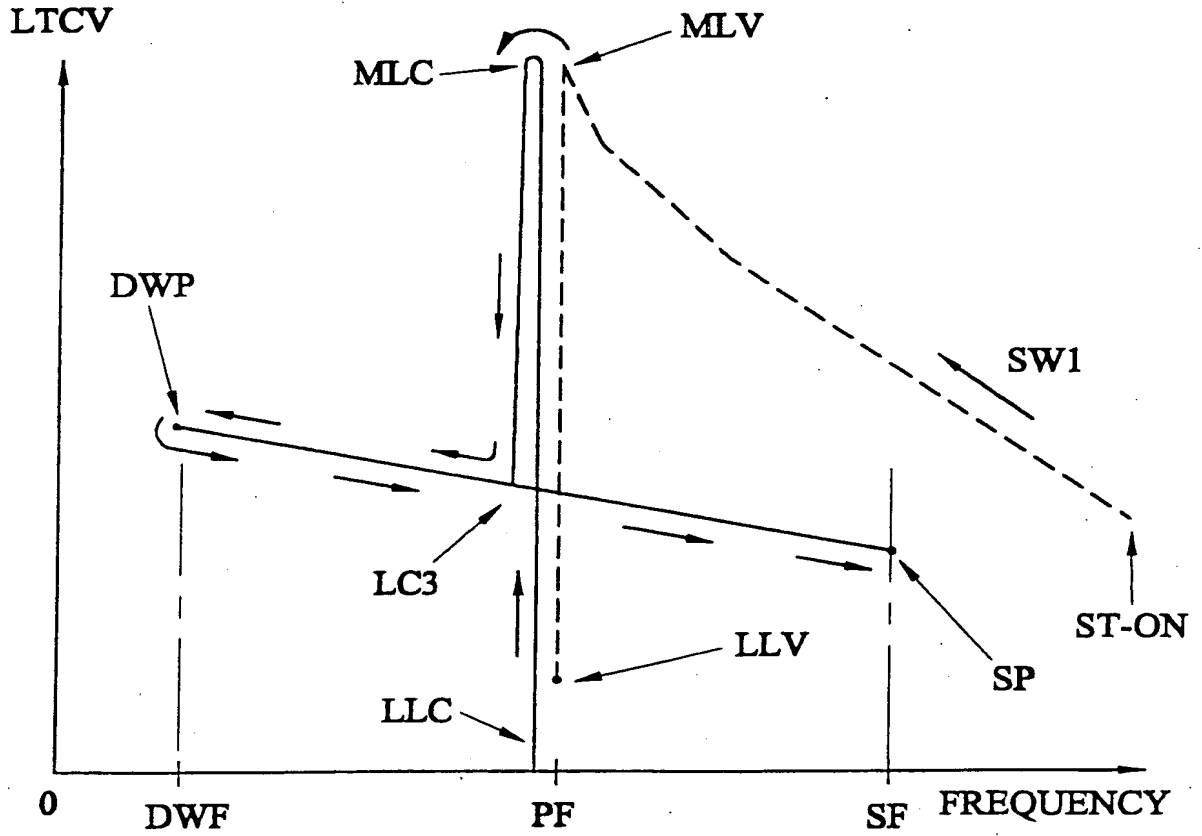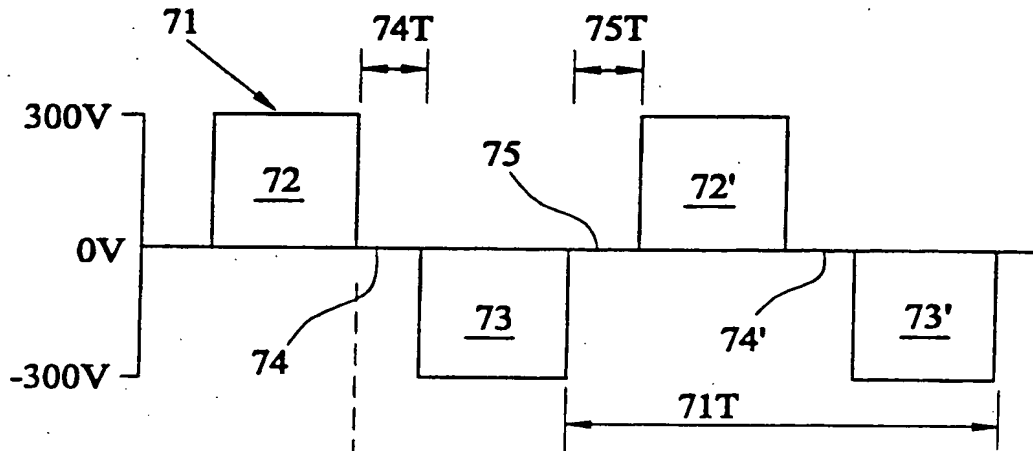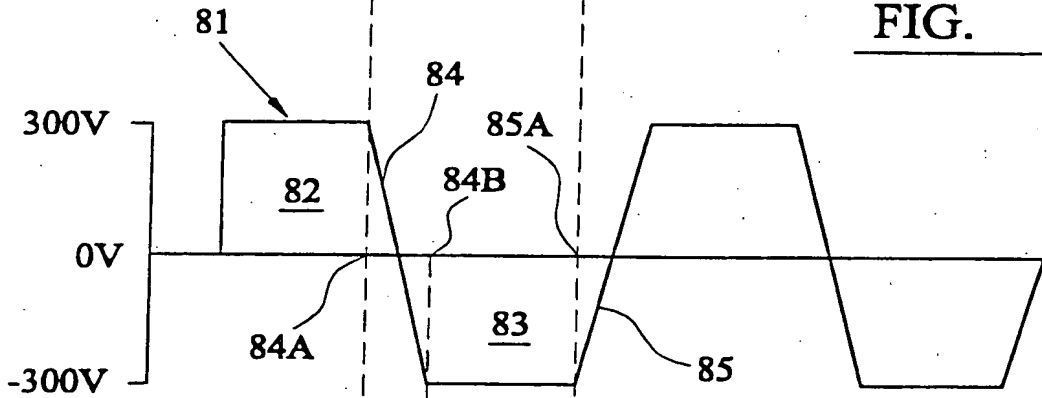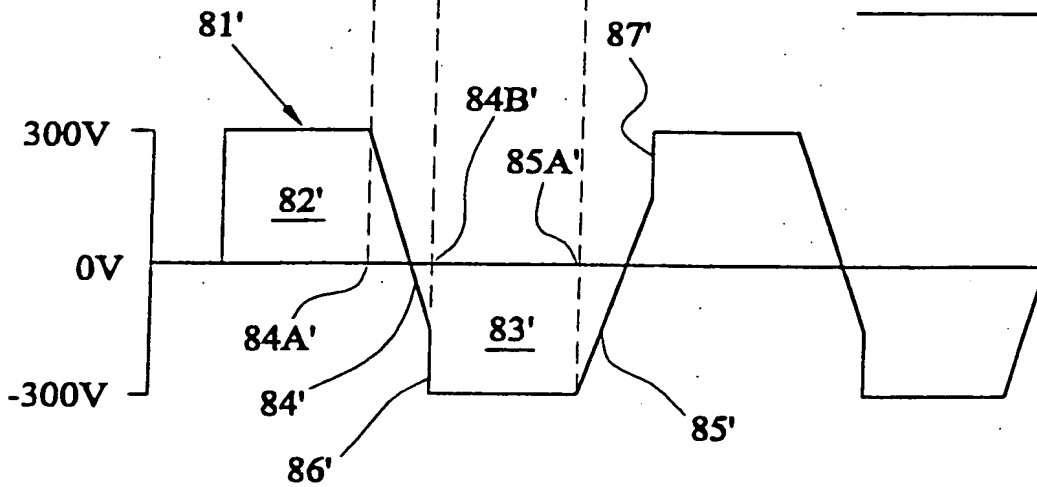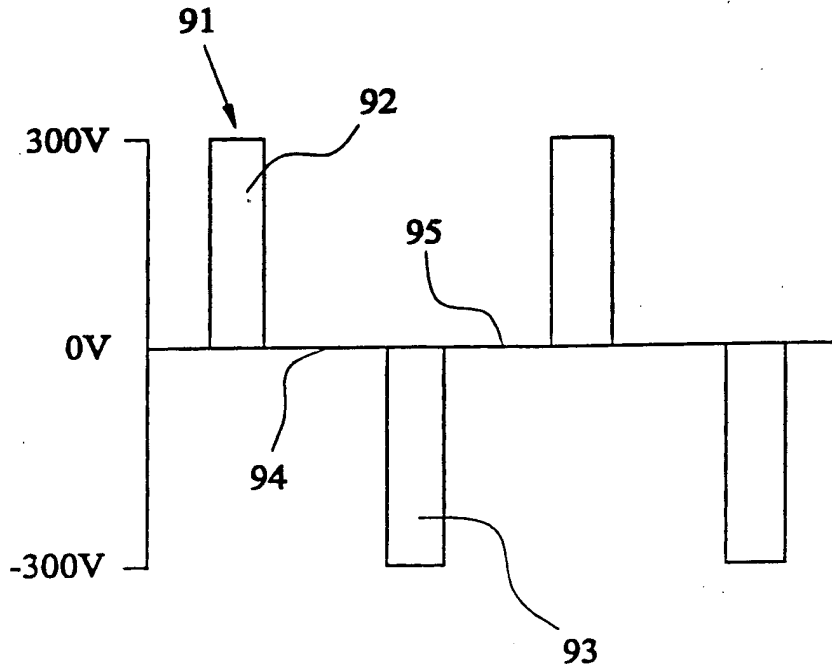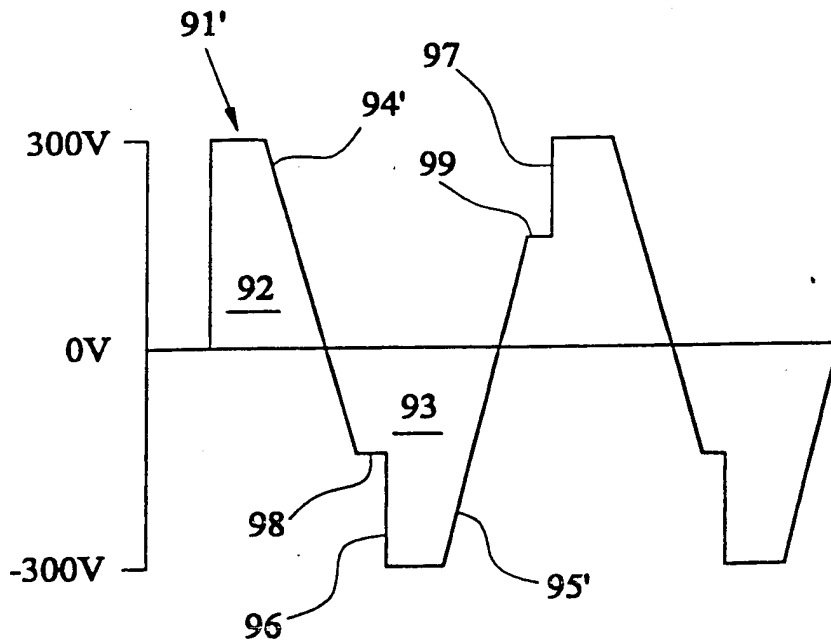
VOLTAGE

PV3

4R'

4XF'

4MF'

RF3

FREQUENCY

FIG. 3

CURRENT

4PC

4R

Capacitive

Inductive

4LL

4XF

4RF

4MF

FREQUENCY

FIG. 4

PHASE

90°

0°

Capacitive

Inductive

-90°

4RF

FREQUENCY

FIG. 5

FIG. 6

71

74T   75T

300V

72   75   72'

0V

73   73'

74   74'

-300V

74   73

71T

FIG.   7

81

84   85A

300V

82   84B

0V

85

84A   83

-300V   85

FIG.   8

81'   87'

300V   84B'

82'   85A'

0V

84A'   83'

84'

-300V   85'

86'

FIG.   8A

● ●

FIG. 9

FIG. 9A

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   H05B41/288

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   H05B   H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 794 694 A (BOSCH GMBH ROBERT) 10 September 1997 (1997-09-10)	1,3,4,9
Y	the whole document	2,5-8, 10,11
Y	BRANAS C ET AL: "ELECTRONIC BALLAST FOR HPS LAMPS WITH DIMMING CONTROL BY VARIATION OF THE SWITCHING FREQUENCY. SOFT START-UP METHOD FOR HPS AND FLUORESCENT LAMPS" ANNUAL CONFERENCE OF THE IEEE INDUSTRIAL ELECTRONICS SOCIETY,US,NEW YORK, NY: IEEE, 1998, pages 953-958, XP000801205 ISBN: 0-7803-4504-5 page 956, left-hand column, line 4 -page 956, right-hand column, line 16; figures 1,5,6,9	2,6,7

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|X| Further documents are listed in the continuation of box C. |X| Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
9 March 2000	15/03/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Speiser, P.

Application No
PCT/GB 99/03851

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
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